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Liaisons dans les structures métalliques

Verbindungen in Stahlstrukturen

Connections and Steel Structures

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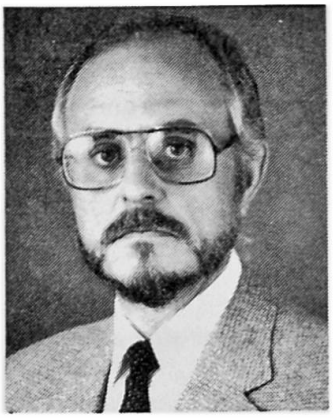

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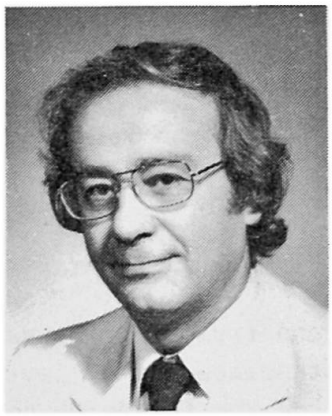

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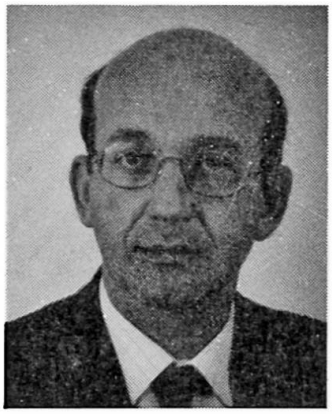

RÉSUMÉ
Cet article présente les principaux enseignements qui peuvent être tirés d'un colloque international organisé en 1987 à Cachan (France) sur le thème des liaisons semi-rigides dans les structures métalliques. Les connaissances scientifiques ont évolué très rapidement dans ce domaine et de nombreux résultats sont utilisables. Les travaux qui restent à développer pour une pratique industrielle courante sont définis tant en ce qui concerne les méthodes simplifiées que les états limites à adopter dans un cadre réglementaire.

ZUSAMMENFASSUNG
Dieser Aufsatz stellt die Haupresultate aus einem internationalen, 1987 in Cachan (Frankreich) organisierten Kolloquium über halb-starre Verbindungen in Stahlstrukturen dar. Die wissenschaftlichen Kenntnisse auf diesem Gebiet entwickelten sich sehr schnell und zahlreiche Ergebnisse sind schon zur Anwendung gekommen. Weiter zu entwickelnde Arbeiten zum Zweck von geeigneten industriellen Anwendungen wurden festgelegt sowohl was die vereinfachten Berechnungsmethoden als auch die im Rahmen der Normen anzunehmenden Grenzzustände betrifft.

SUMMARY
This paper presents the main conclusion of an international seminar which was held at Cachan in 1987 (FRANCE), on semi-rigid connections in steel structures. In this area, scientific knowledge has grown very quickly, and now numerous results are applicable. The work which has still to be done for a practical industrial application is presented not only for the concern of simplified methods but also for the limit states criteria to be adopted within a load and resistance factor design format.

1. INTRODUCTION

During the last five years much research work on semi-rigid connections has been conducted and a lot of data is now available. Partly, this is due to the computational and testing facilities which allow now studying and modeling of highly non linear and three dimensional problems that caracterize the semi-rigid connections. An International Workshop entitled "**Connections, and behaviour, strength and design of steel structures**" was held to bring together a group of researchers and designers with extensive experience in the theoretical and practical areas in order to establish a state of the art and to propose some guide-lines for design code writers.

Furthermore, it was felt that two important functions of the workshop would be :
- To identify the main topics of future research
- To organize and to set up a coherent data base to display the various resources available of reliable information among researchers, designers and code writers.

2. WORKSHOP ATTENDANCE AND ORGANIZATION

To achieve the most in depth, and fruitful discussions of the different aspects of the problem, the workshop attendance was by invitation limited to a relatively small group of experts from the following countries : Australia, Austria, Belgium, Canada, Denmark, France, Italy, Mexico, The Netherlands, Poland, Sweden, Switzerland, United Kingdom, United States, West Germany.

The workshop program was organized in such a manner that the maximum time was devoted for discussion in order to encourage informal exchange of ideas and information.
The following technical sessions were set up :

N°1 : Local analysis of joints
N°2A, 2B : Modeling of load-deflection behavior. Classification
N°3 : Methods of frame analysis
N°4 : Frame stability and simplified methods
N°5 : Design requirements and codes
N°6 : Data base organization.

In addition to the reporter in charge of each session, there was a research reporter whose duty was to inventory research and development needs.

3. TECHNICAL SESSIONS : TOPICS AND DISCUSSIONS

3.1 Local analysis of joints

This session was intended for a review of current theoretical and experimental research dealing with the local behavior of actual connections including all

connecting parts, fasteners, welds and so on. The expected outcomes were the understanding of the failure mechanisms and the identification of the load-deformation controlling parameters.

The main remarks and conclusions are :

- From the theoretical and numerical point of view, the recent finite element methods allow now for the analysis of one, two and three dimensional problems. Material and geometrical properties are considered, as well as contact and slip resistant problems. The separation of individual effects is possible which is of first interest for parametric investigations. Nevertheless some calibration tests are necessary to support and to make operational these methods.

- In the field of experimental work it is recognized the importance of the three dimensional analysis of the behavior of the connections, which are now assessed by new testing facilities. This covers the connections as well as the material itself. Also the unloading behavior should be more systematically studied.

- Concerning the design detailing and code requirements the main need resides in unified concepts and criteria for serviceability and ultimate limit states of the connecting part as well as for the global connection. For example it was thought more adequate to use the ultimate strength of the material rather than the yield stress to determine the strength capacity within an ultimate limit state design format.

- A particular attention was given to the prying force in end plate type of bolted connections. There is a consensus to incorporate the prying effect on the load side of the design equation.

3.2.1. Modeling of load deflection behavior

It was recognized that the global modeling (i.e. moment-rotation curve) is the only possible way to analyse frames with semi-rigid connections.

Many global connection models have been developed and presented. However, the need for assessing the influence of various details was stressed during the discussion. For example the use of slotted holes, to facilitate the erection work, have a significant role in the moment-rotation characteristics which must be taken into account in the modeling.

Although it was agreed that it is preferable to utilize global connections models, it is still necessary to determine carefully the main parameters such that initial stiffness and ultimate strength. Moreover, some global models in use refer specifically to these parameters.

Column footing connections bring up a lot of specific questions regarding unilateral contact problem, anchor bolt bound failure, grouting, crushing of concrete more especially under cyclic loading. In spite of these uncertainties it was recognized that column footing connections are able to have a sufficient amount of end restraint capacity.

Regarding the cyclic loading in general it subsits some particular complex problems with regard to the behaviour of the connection within the range of reversal loading.

3.2.2. Classification

A special sub-session was devoted to the classification of connections into categories such as flexible, semi-rigid, rigid from both experimental and theoretical standpoint. It was largely agreed that a classification system must be given in terms of STRENGTH, STIFFNESS and DEFORMATION CAPACITY. Among these three main parameters the initial stiffness is recognized as the most important controlling parameter for the frame analysis and behavior. So it is necessary to define it more precisely and particularly regarding the perturbation which may happen due to the testing procedure at the start of the loading which may alter the moment-rotation curve definition.

The unloading stiffness seems to be the same that the one in loading, this point have to be checked for a large range of connection types and sizes. This is important for the stiffness definition, on the one hand, and for the stability of frames on the other hand.

With regard to the definition of initial stiffness and ultimate strength some suggestions for simplified moment rotation curve were made (bilinear or trilinear).

As an outcome of the workshop the authors propose a classification system for the beam to column connections based on a reference length and ultimate strength of the connected beam.

3.3. Frame analysis

Different frame analysis computer programs were presented, all taking into account the P - Δ effects. Differences reside in the way the global response of the connection is treated, either discrete plastic hinges, or gradual spread plastification in the members, and so on. Despite these differences the analytical results correlate very well. These programs are mostly research tools and it is still necessary to develop additional design-oriented programs.

The use of semi-rigid connections generally induces lateral drift in the frame, which is the controlling factor in the design process. However, it is possible to find economical solutions which satisfy the drift limitation requirements.

Numerous points were raised regarding the use of composite girders which result in a more flexible bare frame if the slab stiffness and continuity is not taken into account in the calculation. In fact, composite action is able to provide a significant amount of end restraint.

3.4. Frame stability and simplified methods

There are now practical and design-oriented approaches to column and frame stability with semi-rigid connections. From experimental studies it was found a good correlation between the stability problems of individual columns and columns in subassemblages and frames. More particularly, the column stability solution seems to have a wide application area.

Concerning the simplified methods it was pointed out that they are the only way to bring effectively the semi-rigidity concepts into practice. In these methods the initial stiffness is of first importance. However the initial stiffness for the column footing connections depends on the moment-axial load interaction, longterm effect and cyclic loading. So additional research is needed to clarify the importance of these effects.

3.5. Design requirements and codes

There is a general agreement to recognize that the only practical way to make use, and to design semi-rigid connections was to refer to limit states design format.

It was pointed out that revised drift limits would have to be developed for frames with semi-rigid connections and that the commonly used limit of 1/400 for the ratio of building drift to building height have been established for structures with rigid joints taking implicitly into account the deformability of the connections. More accurate evaluation of lateral displacement leads to define more realistic drift limits. As said in the local analysis session, the limit states requirements for individual fasteners have to be known and fixed precisely.

Another question is to know if it is possible to introduce new steel quality and grades in the current design standards which are mainly based on the mild structural steel properties. There is a consensus to give a positive answer as long as, yield ratio, ductility ratio and weldability are warrantied. In the same way it is suggested that design standards should establish in parallel scopes and knowledge dissemination documents to establish or justify their background information.

3.6. Data base organization

There is a general agreement to recognize that this subject is of significant interest for a proper organizational structure allowing exchanges of information as well as avoiding any duplication of work. The first task of this organization is to provide a data sheet format available for researchers and designers for actual construction projects. This data sheet must contain all information for material properties of members and connectors, drawings of connections and testing devices, loading and measurement procedures and so on. The results have to be given in load-deflection curve indicating serviceability and ultimate load as well as initial stiffness which may be obtained by a partial unloading path. In the future this data base organization could be implemented and processed through a computer network such as E.A.R.N.

The contact persons for the data base organization are :

Reidar Bjorhovde (USA) and Jacques Brozzetti (France) for the beam to column connections.
Frans Bijlaard (The Netherlands) and Denis Beaulieu (Canada) for the column footing connections.

4. CONCLUSION

For the participants, the first benefit of this workshop is a better knowledge of each other through truly in-depth exchanges of opinions, methods, procedures, results and future directions and this for a wide number of countries.

There were agreements on the necessity of :
- improving the limit states design codes for allowing a better account of the semi-rigid connection concepts.
- setting up new simplified, and accurate, methods.
- a classification system of connections with regard to their main behavior.
- a data base organization.

A large number of propositions has been done to achieve these goals both with the identification of the more interesting research and development needs.

5. ACKNOWLEDGEMENTS

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